FEDERAL COMMUNICATIONS COMMISSION

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EXHIBIT NO. 593

"Very-High-Frequency and Ultra-High-Frequency Signal Ranges as Limited by Noise and Co-channel Interference." E. W. Allen, Jr., Federal Communications Commission (*1*).

The above subject is extremely broad, and no exhaustive treatment can be given in this paper. However, an attempt will be made to summarize the various major factors affecting radio wave propagation in the frequency range from 30 to 3000 mc to the extent to which they are known or can be predicted at the present time, and to estimate the probable service and interference ranges for broadcast and land mobile services within this part of the frequency spectrum. The theoretical ground wave service ranges with simple antennas are first considered and the possibilities of increasing the ranges by the use of transmitting and receiving antenna gain are discussed. Factors which may modify the theoretical ranges are then considered in the following order: external noise levels, terrain, tropospheric propagation effects, long distance F layer and Sporadic E layer interference.

Ground Wave Ranges.—Theoretical ground wave ranges have been computed (*2*) for frequency modulation and television broadcast stations, land stations to mobile ranges, and mobile to mobile ranges throughout the frequency band under consideration. These ranges are plotted in Figure 1, which shows the distances in miles vs frequency to the 500, 50, and 5 uv/m contours for broadcast stations of 1 kw and 50 kw effective radiated powers, to the 4 uv rural receiver input contour for the 50 kw broadcast station, to the 0.4 uv mobile receiver input contour for a 250 watt land station in the mobile service, and to the 0.4 uv receiver input contour for 50 watt mobile to mobile operation. For the broadcast stations the transmitting antennas are half wave dipoles located at 1000 feet above the surrounding area. The receiving antennas are at a height of 30 feet and for the 4 uv receiver input curve a half wave dipole is assumed. For the land station a vertical half wave dipole 100 feet above ground is taken as typical. Mobile units are assumed to use a quarter wave vertical antenna mounted in the center of the top of the vehicle at 6 feet above ground.

The theoretical 4 uv rural broadcast receiver contour assumes that reception is limited by 1 uv of set noise, over which 2 uv of actual signal on the set terminals will provide a useful signal. This allows or a 6 db attenuation from the theoretical due to terrain and losses in the receiving antenna leadin. It is evident that the indicated ranges can be obtained only in very quiet rural areas where the external and undesired noise field strengths are less than one half as strong as the desired signal. Also a good receiver with a low noise level and a 2 to 1 noise and co-channel rejection is required. While the assumption of a higher required receiver input voltage will reduce the absolute values of the service ranges accordingly, the relative ranges with respect to frequency are not affected appreciably. The 0.4 mobile receiver contours likewise provide for an additional attenuation of 6 db below the theoretical, and assume that 0.2 uv of signal at the set terminals is sufficient to override set noise of 0.1 uv.

The theoretical curves show that distances to the 500 uv/m service contour of the 1 kw broadcast station increase with frequency throughout the band, while for 50 kw the distance increase up to about 1000 mc, after which a slight decrease occurs. For the 50 uv/m service contour the change is less marked with frequency, a slight increase in distance being noted for the 1 kw station up to 500 mc, while the maximum distance for the 50 kw station occurs at about 70 to 80 mc. The maximum range of the 5 uv/m interference contour occurs at 50 mc and decreases thereafter for the 1 kw station but decreases with frequency throughout the band for a 50 kw station. In general it may be said that the protected service ranges increase and the interference range decreases with frequency. In contrast, the rural FM broadcast range, and the mobile service ranges decrease rather rapidly with frequency.

Effects of Antenna Gain.—If a road clearance of 10 feet is assumed for the mobile units, it will not be possible to use a top mounted quarter wave antenna at frequencies below 60 mc. Aside from directional effects, however, a bumper mounted antenna will be just about as effective at these frequencies as a top mounted antenna, and will not disturb the theoretical ranges materially. Top mounted half wave antennas should be practical beginning at about 150 mc and multiple bay antennas from 300 mc upward. Use of the higher frequencies will also make other types of high gain antennas practicable. Since the signal to external noise ratio will vary directly with the transmitting antenna field gain and the signal to set noise ratio will vary as the product of the transmitting and receiving antenna field gains, it is probable that high gain mobile antennas will be adopted above 300 mc in order to increase the limited range of mobile to mobile contact.

It will be noted that the 4 uv rural contour crosses the 50 uv/m contour of a 50 kw broadcast station at 600 mc. Consequently, at higher frequencies it appears to be expedient to protect a higher contour, or set noise rather than co-channel station interference will be the limiting factor. An alternative to increasing the contour is to assume the use of a high gain antenna at the receiving location. Antennas with a field gain of 2.5 or more appear to be of a practical size for home use at 100 mc and above (*3*).

The broadcast ranges and land station to mobile range can be increased by increase of power, antenna gain, or antenna height. Theoretically, the preferred method is by increasing antenna height, as this results in an increased service range without a material increase in the skywave and tropospheric interference. Next in order of preference is antenna gain, as this tends to discriminate against high angle radiation which may cause interference. However, available transmitter sites and economic factors generally result in a balance which is not optimum from the standpoint of minimizing interference. There are also certain limitations on the amount of antenna gain which can be used. First, there are practical limitations, which at frequencies below 50 mc, appear to limit the power gain to about a factor of 10 for a turnstile antenna. Secondly the gain in the horizontal plane cannot be so great that the antenna does not provide a sufficient field in the area below the antenna.

Figure 2 shows the results of a theoretical investigation to determine the probable limits on gain from the latter cause. In Figure 2, the ordinates represent relative field strengths and the abscissae are the angles of radiation $\emptyset$, 0° being in the horizontal direction and 90° straight downward or upward. The antennas are assumed to be elevated above an urban area which requires a signal level of 1 mv/m to overcome the ambient noise. The strength of the radiation in a particular direction which is required to produce a field of 1 mv/m at the receiving antenna is dependent upon the distance between the transmitting and receiving antennas and upon the relative phases of the direct and ground reflected waves. If we let R_o be the ground reflection coefficient at any angle $\emptyset$ and H the antenna height, the maximum and minimum limits of the required radiation E_o at the angle $\emptyset$ from the transmitting antenna to furnish a field strength E at the receiving antenna are given by the equations $E = E_o (1+R_o) (\sin \emptyset)/H$, for receiving sites in which the direct and ground reflected waves reinforce each other, and $E = E_o (1-R_o) (\sin \emptyset)/H$, in which they tend to cancel each other. The first formula yields the family of solid curves (A,B,C,D,E) and the second formula yields the dashed curves (A,B,C,D,E,F,G) for an effective radiated power of 1 kw (137.6 mv/m free space field at one mile) and antenna heights of 10,000; 5000; 2000; 1000; 500; 200 and 100 feet. The curves are also applicable to other powers and antenna heights in accordance with the table shown. Typical conditions of effective radiated power and antenna height are confined to curves E and below.

Superposed on the limiting directivity curves are vertical directivity patterns for a 10 bay turnstile (solid) and for a 20 bay turnstile (dashed) antenna. It is believed that we may neglect the deep nulls shown by the calculated patterns at large angles from the horizontal, as but a slight current unbalance in the separate bays is required to fill them materially. The zones around the antenna corresponding to these nulls will also tend to fill in, owing to reflections and reradiation from buildings and other objects. The nulls at small angles of 10° or less require a much larger current unbalance to fill in, but for high antennas the radiation in this part of the pattern may be directed beyond the area of high noise level. At the lower end of the frequency band under consideration the direct and ground reflected waves do not cancel for small angles so that the solid lines more nearly represent the limiting conditions.

The limits are well below the 20 bay pattern and it may well be that the limitations on directivity will be practical rather than theoretical throughout the band under consideration. However, as the frequency increases there will be an opportunity for employing types of transmitting antennas other than the turnstile to which present practical difficulties may not apply.

External Noise Levels.—Having compared theoretical ground wave service and interference ranges for the band under consideration, let us consider in the following order the major factors which are expected to modify the theoretical predictions: external noise levels, terrain, tropospheric propagation effects, long distance F layer and Sporadic E layer interference and Bursts.

The 50 uv/m contour for FM and the 500 uv/m contour for television were chosen so as to give the required protection from average values of external noise encountered in rural areas. These contours may therefore be modified upward or downward in accordance with the experience as to noise levels to be encountered on the various frequencies (*4*).

The 4 uv contour is based upon the assumption that the external noise level is so low that the internal receiving set noise is the limiting factor. The presence of external noise of sufficient value to become the limiting factor rather than set noise will change the slope of the curve to conform more nearly to the slopes of the 5 uv/m and 50 uv/m curves, the absolute distances being dependent upon the external noise levels encountered at various frequencies. External noise will likewise reduce to a greater extent at lower frequencies the service ranges to the 0.4 uv mobile contours. However, present information indicates that the residual service ranges will continue to be considerably greater at the lower end of the band.

Terrain.—Irregularities in terrain, such as hills and buildings are expected to cast deeper shadows at the higher frequencies but much work remains to be done to evaluate these effects. This is believed to be especially important for mobile services where mobile transmitting antennas, and frequently the land station antennas, are not elevated above immediately surrounding buildings. For elevated broadcast antennas the shadows will tend to fill in behind building by reason of reflections from buildings beyond the shadow. Shadows behind hills in rural areas probably will not fill in as well as behind city buildings, and it is expected that somewhat more difficulty may be found in serving hilly areas at the higher frequencies.

There is evidence which indicates that frequencies around 100 mc do not penetrate buildings and other structures as well as do frequencies at the lower end of the band (*5*). Whether this trend will continue with increasing frequency is not known, but it is quite possible that when the wavelengths become short in comparison to openings which are surrounded by closed conducting circuits (steel building skeletons, metal window and door frames, etc.) the penetration may improve with increasing frequency. The poorer penetration at some frequencies will affect not only the field strengths of the desired signals but also the field strengths of undesired signals and of noise, if the noise source is removed some distance from the receiving point. It does not appear to be possible to predict what effect differences in penetration will have upon the ratios of desired to undesired signal and signal to external noise which are obtainable with an inside antenna at typical receiver locations. The only answer lies in making comprehensive surveys of signal and noise field strengths at receiver locations. If, as a result of such surveys, it is established that poorer penetration exists at some frequencies but that signal to external noise ratios are not appreciably affected thereby, it is evident that at some locations with low signal intensity it will be necessary to use an outside antenna to overcome receiver noise for a frequency with poor penetration whereas an inside antenna would be usable for a frequency with good penetration. Only quantitative measurements can establish whether this condition will occur within the protected contours at any given frequency.

Tropospheric Effects.—Our present knowledge of tropospheric effects does not extend over much of the band under consideration. Continuous recordings of FM and Television stations have been made by the F.C.C. over a period of about two years. A year's recordings of FM stations made at four distances were analyzed to determine the fields exceeded for 0%, 10%, 50% and 90% of the time, the 100% value being below noise level in each case. These fields were reduced to equivalent values for 1 kw radiated from a half wave antenna to 500 feet and plotted at the proper distances in relation to K.A. Norton's theoretical ground wave and tropospheric wave curves in Figure 3. The theoretical ground wave curves agree with the measured values exceeded for more than 90% of the time and appear to be a relatively reliable measure of service ranges. The maximum measured values greatly exceed the theoretical so that in order to protect adjacent stations, the distance to the 5 uv/m interference contour may need to be doubled. Measured values at 72 mc were also found to verify the theoretical service ranges. The fields were somewhat more variable than at 46 mc so that the interference range should be increased by something more than a factor of 2 (*6*).

Quantitative data similar to the above are not available on higher frequencies. The experiences of amateurs on 112, 224, and 400 mc represent probably the best published data. The 112 mc reports are in agreement with the trend indicated at 44 and 72 mc; namely the greater variability of the tropospheric effects with increasing frequency and the necessity for greater station separation to prevent interference due to tropospheric signals. Under favorable troposhperic conditions and with high transmitter and/or receiver locations, amateur stations have been heard over distances between 350 and 400 miles at 112 mc (*7*). The long distance contact records are less at 224 and 400 mc but this may be due to the lesser activity and to equipment development rather than to a change in the trend of tropospheric effects.

F Layer Interference.—The best data on this subject are the regular ionosphere measurements which have been made for many years at the National Bureau of Standards' laboratories near Washington, D.C. and more recently have been made at a very large number of other points throughout the world. These recent measurements have been made by the Interservice Radio Propagation Laboratory under the joint control of the Army and Navy. The Washington measurements have been made throughout a period including the maximum of one phase of the sunspot cycle. The published data (*8*) for Washington for monthly average values during the winter months October through March of the three winters centered about the sunspot maximum (1936–37, 1937–38 and 1938–39) were corrected for daily variations and analyzed so as to express critical frequencies as a percentage of the listening hours, 6 AM to midnight, solar time. Using methods formulated by the Bureau of Standards, the critical frequencies (maximum frequency reflected at vertical incidence) were converted to values of maximum usable frequency versus distance. These data are plotted in Figure 4.

Suppose we had had an FM station operating on 44 megacycles during the maximum of the last sunspot cycle. Then according to Figure 4 we would not have expected any F layer reflections at distances less than 1320 miles. However, we would have expected F layer transmissions at all distances greater than 2060 miles for 1% or more of the listening hours or for a total of 723 hours during the last sunspot cycle. On a frequency higher than 60 megacycles, however, we would not have expected any F layer transmissions at any distance provided the transmission path had its midpoint near Washington, D.C. It has been found that the ionosphere directly over many of the other stations would be expected to support much higher frequency transmissions than the ionosphere over Washington. The best estimate which we are able to make is that the frequencies shown in Figure 4 should be increased by 15% when considering conditions applicable to interference throughout the United States. In other words the present 40 mc on the horizontal scale should be renumbered 46 mc, the 60 mc should be 69 mc, etc. The foregoing analysis of conditions during the last sunspot cycle will not apply strictly to future conditions, since we know that the numbers and intensities of the sunspots vary from cycle to cycle. There is also a reversal in sunspot polarity on alternate cycles which may have some effect. However, they are the only data available and we must make the best prediction we can from them.

Figure 4 applies to the estimated interference via F layer from a single co-channel station. To what extent will an increase in the numbers of stations on a single channel increase the expected time of interference? Assume a 46 mc station in New York City with six co-channel stations of about the same power located at Athens, London, Georgetown, Bogota, San Francisco and Honolulu. Figure 5 is a section of a world map showing the paths under consideration. The Georgetown, Bogota and San Francisco paths are 2500 miles in length and transmission is assumed via one reflection point at the F layer. The Athens, London and Honolulu paths involve two reflections at the layer. For simplicity's sake, the assumption will be made that the F layer conditions do not vary between the latitudes represented by the northmost reflection or control point (2) and the southernmost control point (4). This is not in accordance with the

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facts but will provide an approximation which is believed to be on the conservative side if average conditions for the United States are used. The vertical lines on the map are meridians of longitude at 15 degree intervals, so that they are separated by one hour's difference in time. Each meridian is marked at the bottom with the New York time corresponding to noon at the meridian. Assume a winter day near the sunspot maximum on which we would experience from one station at 2500 miles four hours of interference, beginning at noon at the control point and continuing until 4 PM at the control point. For the Athens-New York circuit, the interference at New York would begin at noon at the westernmost of the two control points (1) and end at 4 PM local time at the easternmost point. These times correspond to about 10:20 and 10:50 New York time, yielding 30 minutes of interference as shown by the duration chart at the bottom of the Figure. The duration of interference can be similarly estimated for the other paths, which when totalled gives about 7½ hours of interference as against 4 hours for one station. Similar analyses for other periods of expected interference from a single station will show that the ratio of multi-station to single station interference increases somewhat with decreasing times of single station interference. This is expected to increase the ratio slightly when estimating the overall percentage of time throughout the sunspot cycle, so that the multi-station interference may finally be about three times the estimated single station interference.

Sporadic E Layer Interference.—Again the best data available for determining the practical importance of these transmissions at various frequencies are the systematic observations of the ionosphere made by the Interservice Radio Propagation Laboratory. Figure 6 shows Sporadic E layer skip distance as a function of frequency for various percentages of the listening hour during the year September 1943 through August 1944 estimated from measurements of Sporadic E layer critical frequencies made near Washington, D.C. This particular year was chosen for analysis since it was for this year that the Sporadic E layer field intensities of WGTR were measured at several F.C.C. monitoring stations. An analysis of similar data obtained at two other ionosphere stations at widely separated points in the United States and for the same period of time yielded very nearly identical results. The Washington data, which are available throughout one phase of the sunspot cycle, did not indicate any systematic variations throughout this last cycle, but did indicate that the conditions for the period analyzed were about average. Consequently Figure 6 is believed to represent a reasonably good estimate of the percentage of time that a single FM or television station would be expected to interfere with another similar station on the same frequency at the distance shown. At 43 mc, interference is expected between 0.1% and 1.0% of the time for distances between 600 and 1400 miles.

In an effort to obtain an estimate of the effect of increasing the numbers of stations on the occurrence of Sporadic E interference Figure 7 was prepared. This is a map of the central and eastern parts of the United States on which has been located the E layer control points (1), (2), (3), (4), for the paths over which station WGTR was measured at the F.C.C. monitoring stations at Atlanta, Laurel, Allegan and Grand Island. Control points (A) to (I) are also shown for paths by which interference might be caused to a Kansas City station by stations located in nine cities 800 miles from Kansas City and 300 miles or more from the adjacent cities. A reliable estimate of the interference to be expected at Kansas City under the assumed conditions will require an extended analysis of available data, which has not been possible to date, together with further knowledge of the mechanism of Sporadic E reflections. However, a simplified analysis may permit us to make an educated guess as to what may be expected.

Over the period September 1943 through August 1944 Sporadic E fields of 25 uv/m were recorded for 1.71% of the time for path (1), 0.05% for path (2), 0.39% for path (3) and 0.55% for path (4). There was some overlap in the times during which transmission occurred, the combined time being 2.23% for all paths, against 2.70% for the arithmetic sum. Thus three additional paths with a total of 0.99% added 0.52% to the occurrence over path (1). This appears to indicate that three additional paths with control points of comparable distance from point (1) and each having 1.71% would have raised the multi-path interference to 4.40%. Applying the ratio to the Kansas City case of nine paths, each over a distance likely to give 1.71% occurrence of Sporadic E, we obtain a total of 8.89%. Considered solely from the standpoint of probability, the ratio 52/99 which applies to the case of three additional stations with small percentages of interference is too high for eight additional stations each causing a large percentage of interference, assuming comparable spacings between control points. Increased control point spacing in any direction will tend to increase the ratio because of the apparently random nature of the Sporadic E layer at times (*6*). Increased spacing east and west should increase the ratio owing to systematic diurnal effects. For the present it will be assumed that latitude effects are cancelled since control point (1), which has been used to estimate quantitatively the interference over each path, is at an average latitude. Interference from ten to fifteen additional stations spaced at other distances from Kansas City will of course add materially to the overall time of expected interference. Considering all the factors, it appears probable that a midwestern station with twenty co-channel stations may experience interference amounting to five or more times the estimated interference for a single path.

Sporadic E and F Layer Field Strengths.—Figure 8 shows curves of the variation of tropospheric, Sporadic E and F layer field strengths with time and distance for Station WGTR, Paxton. The F layer curve is a theoretical curve of the variation of F layer median field intensities, and the intensity at any distance approximates the free space field at one mile divided by the distance in miles. For Sporadic E a family of curves were computed from data obtained under the F.C.C. FM recording program. The curve (lp) shows expected field strengths versus distance for the percentages of time predicted by the curves of Figure 6, the maximum occurring at about 900 miles. For lesser percentages of time (0.25 p and 0.5 p) higher field strengths will occur and for greater percentages of the time (2p and 4p) weaker fields will occur at a given distance. The tropospheric curves shown in Figure 8 were prepared from the data used in Figure 3, and their effect on theoretical service and interference ranges has already been discussed in connection with that Figure.

Interference from Bursts.—The measurements made at the same four F.C.C. monitoring stations from several high powered FM stations over a two year period indicate that negligible interference will be caused to the 50 uv/m protected contour from this source (*6*). Although not entirely free of this interference, reasonably good service may be possible to about the 5 or 10 uv/m contour. If the bursts are caused by meteoric ionization, which is the present assumption, the numbers, amplitudes, and average durations should decrease with frequency. This is in agreement with such observations as we have made on the aural channels of television stations and with observations of other persons at frequencies down to about 10 mc (*9*).

Comparison of Service Areas at 46 and 105 mc.—Having considered individually certain factors which affect the service ranges to be expected in the band under consideration, let us consider the combined effect of these factors on FM broadcast service areas. Figure 10 presents a comparison of the service areas to be expected at 46 mc and 105 mc for transmitting stations having a 500 foot antenna. The receiving antennas are at 30 feet in each case and 6 db reduction in the received field is allowed for irregularities in terrain, line loss, etc.

The figures in the top row show the coverage for a large station with an effective radiated power equal to WGTR (340 kw). The inner circle of each figure represents the primary service area to the 50 uv/m contour, within which it is desired to protect the signal from interference by other stations. The primary area at 46 mc is slightly larger than at 105 mc. The outer circle at 46 mc and the middle circle at 105 mc represent the service limits obtainable in very quiet rural areas with external noise sufficiently low so that set noise is the limiting factor, with good receivers capable of delivering a usable signal with a 2 uv input, and with negligible interference from other stations. The extra 46 mc area under these conditions is almost twice as large as the area at 105 mc. By the use of a multiple element Yagi antenna at 105 mc, an extra rural area approximating three fourths of the 46 mc rural area may be obtained. The middle row of figures gives a similar comparison for a station with an effective radiated power of 1 kw. In this case the 105 mc primary area is the larger, with the total area at 46 mc equal in size to the 105 mc area for a Yagi receiving antenna.

Owing to shadow effects, coverage within the primary and rural areas is likely to be somewhat more spotty at 105 mc than at 46 mc. External noise levels will also eliminate large portions of the rural areas, and external noise of a given intensity will become effective against the areas obtainable with the Yagi antenna before it affects the areas obtainable with a half-wave receiving antenna. The tendency to reduce the 105 mc area to a greater extent should be offset somewhat, but not completely, by the decrease in external noise level with frequency. The assignment of other stations to the same channel will limit the useful area to the 50 uv/m contour if they are close. If the co-channel stations are distant, the extra rural areas will be affected by Burst interference at 46 mc and probably, to a lesser extent, at 105 mc. At 46 mc Sporadic E layer and F layer interference from distant stations is expected to affect both primary and rural areas seriously at certain times.

Referring to the left figure of the bottom row on Figure 9, residual areas for a broadcast station are shown for conditions of Sporadic E interference which are expected for 0.1% of the time from a single co-channel station of equal power or for 0.5% or more of the time for a fully utilized channel. The larger station seeks a reduction in its primary area of 46% for good receivers with a rejection ratio and 78% for an average receiver with a 10/1 reject ratio. The 1 kw station sustains a reduction in primary area of 5 for an average receiver. A good receiver will still give service beyond the 50 uv/m contour for these conditions of interference and will permit reduction in service area for an estimated 0.05% of the time for a fully utilized channel.

The effect of F layer skywave interference is shown in the right figure of the bottom row on Figure 9. At 46 mc this is expected to occur about 5% of the time for a single co-channel station with an increase to 10 or 15% for a fully utilized channel. The occurrence of this condition at 105 mc is expected to be negligible. The large station suffers reductions in areas of 86% and 96% for good and average receivers, resp. The corresponding reductions for the small station are 41% and 84%, resp. In order to reduce the skyway from stations separated by 2500 miles to the point where mutual protection will be given to the best receiver at the 50 uv/m contour the effective radiated power of each must be limited to 200 watts.

In addition to contrasting the expected conditions of interference on 46 and 105 mc, Figure 9 shows the importance of using receiver which is capable of rejecting a strong interfering signal. Tests on several commercial models of FM receivers have indicated that single limiter models may require a desired signal more than ten times as strong as the undesired in order to obtain an acceptable output, while the best double limiter receiver tested require about three to one. The service areas obtainable with the good receiver having a two to one rejection ratio are therefore larger than are obtainable with any of the receivers tested.

REFERENCES

(*1*) The paper was originally intended as a joint paper by K. A. Norton, O.C.S.O., U.S. War Dept., and E. W. Allen, Jr., Federal Communications Commission. A large part of the material was prepared jointly, and some of the data and conclusions were entered into the record of the F.C.C. hearing on frequency allcoations, Docket 6651, by Mr. Norton. He has been unable, however, to devote an appreciable amount of time to the final preparation of the paper and has insisted that the presently indicated sole authorship is proper. This has been agreed to, with some reluctance, but grateful acknowledgment is made of the valuable participation of Mr. Norton in the preparation and interpretation of data and of his many helpful suggestions as to its form of presentation.

(2) "The Calculation of Ground-Wave Field Intensity Over A Finitely Conducing Spherical Earth", By K. A. Norton, Proc. I.R.E., December 1941.

(3) "Parasitic Arrays" ARRL Antenna Handbook, 1939, Page 65.

(4) "Field Strength Of Motorcar Ignition Between 40 And 450 Megacycles", R. W. George, Proc. I.R.E., September 1940.

(5) "A Study Of The Propagation Of Wavelengths Between Three And Eight Meters", L. F. Jones, Proc. I.R.E., March 1933. "An Urban Field Strength Survey At Thirty And One Hundred Megacycles", R. S. Holmes and A. H. Turner, Proc. I.R.E., May 1936.

(6) "Report On VHF Field Strength Measurements 1943–1944"; F.C.C. Mimeo 77785; F.C.C. Docket 6651, Exhibit #4.

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"Analysis Of The Effect Of Scattering In Radio Transmission", T. L. Eckersley, Jr. Inst. E.E., Wireless Section, June 1940.

THE VARIATION WITH FREQUENCY OF GROUND WAVE SERVICE
AND INTERFERENCE RANGES

BROADCAST ANTENNAS: HOR. $\frac{1}{2}$ WAVE AT 1000' - 30'
BROADCAST RANGES: 50 KW ——; 1 KW -----
LAND STATION ANTENNA: VERT. $\frac{1}{2}$ WAVE AT 100'
MOBILE ANTENNAS: VERT. $\frac{1}{4}$ WAVE AT 6'
LAND TO MOBILE RANGE: 250 W -·-
MOBILE TO MOBILE RANGE: 50 W ·····

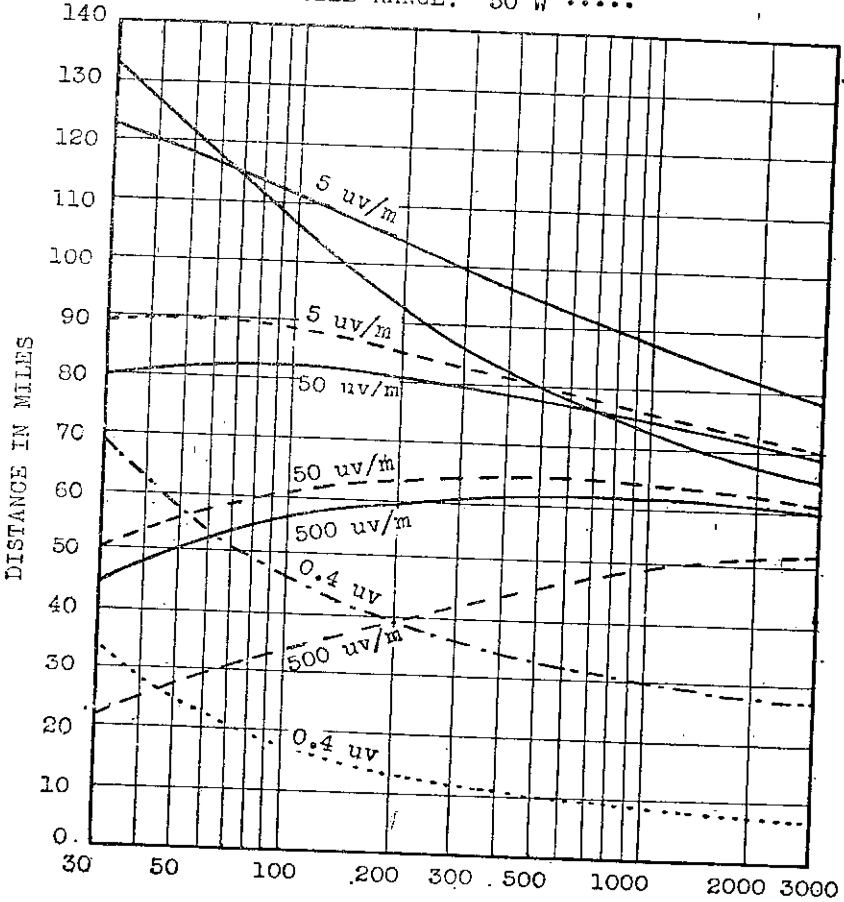


FIGURE 1

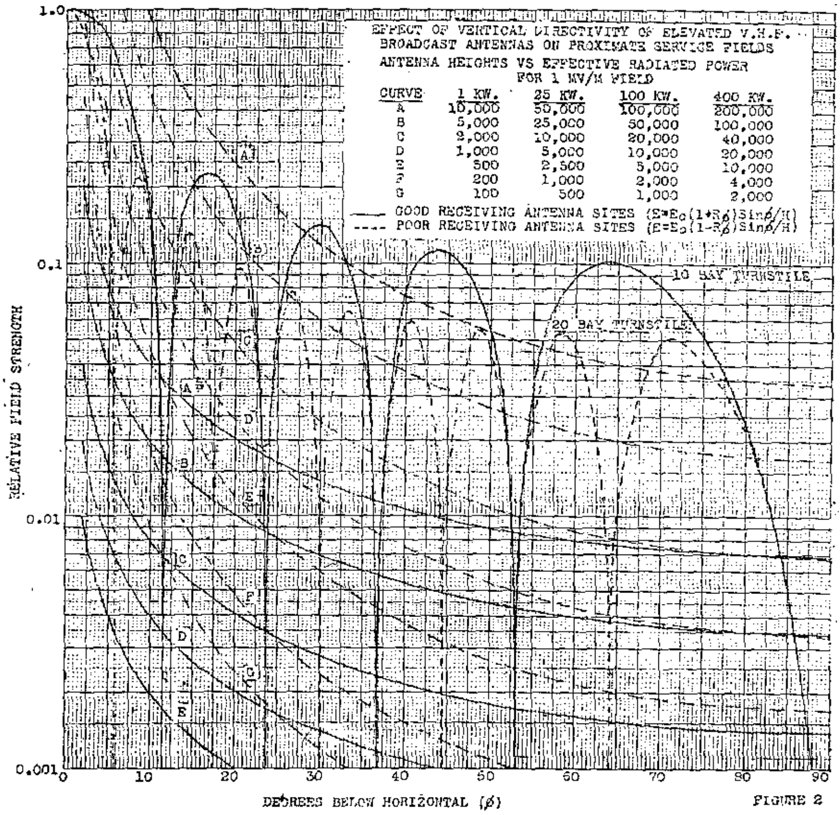
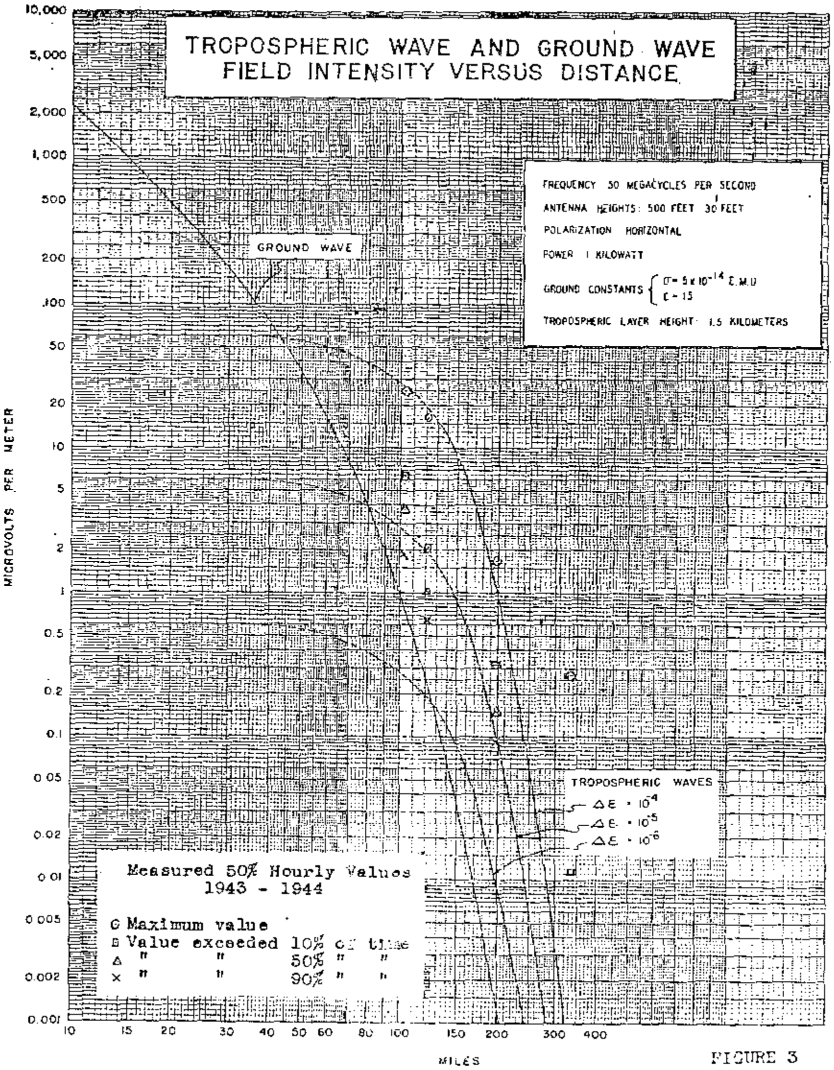
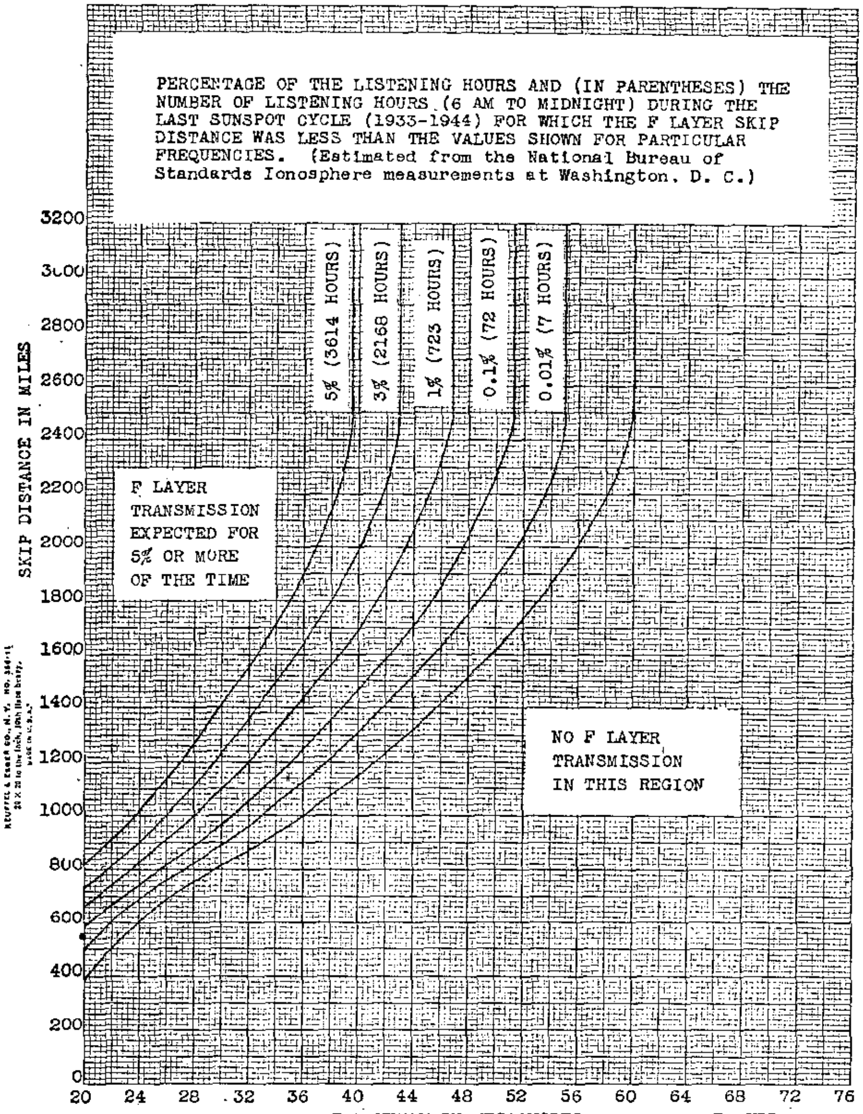

EFFECT OF VERTICAL DIRECTIVITY OF ELEVATED V.H.F. BROADCAST ANTENNAS ON PROXIMATE SERVICE FIELDS
ANTENNA HEIGHTS VS EFFECTIVE RADIATED POWER FOR 1 MV/M FIELD
CURVE 1 KW. 25 KW. 100 KW. 400 KW.
A 10,000 50,000 100,000 200,000
B 5,000 25,000 50,000 100,000
C 2,000 10,000 20,000 40,000
D 1,000 5,000 10,000 20,000
E 500 2,500 5,000 10,000
F 200 1,000 2,000 4,000
G 100 500 1,000 2,000
GOOD RECEIVING ANTENNA SITES (E=E₀(1+R$_\phi$)Sinϕ/H)
POOR RECEIVING ANTENNA SITES (E=E₀(1-R$_\phi$)Sinϕ/H)
10 BAY TURNSTILE
20 BAY TURNSTILE
RELATIVE FIELD STRENGTH
1.0
0.1
0.01
0.001
0
10
20
30
40
50
60
70
80
90
DEGREES BELOW HORIZONTAL (ϕ)

FIGURE 2


TROPOSPHERIC WAVE AND GROUND WAVE FIELD INTENSITY VERSUS DISTANCE
FREQUENCY 50 MEGACYCLES PER SECOND
ANTENNA HEIGHTS: 500 FEET 30 FEET
POLARIZATION HORIZONTAL
POWER 1 KILOWATT
GROUND CONSTANTS σ = 5 x 10^-14 E.M.U ε = 15
TROPOSPHERIC LAYER HEIGHT 1.5 KILOMETERS
GROUND WAVE
TROPOSPHERIC WAVES
ΔE = 10^-4
ΔE = 10^-5
ΔE = 10^-6
Measured 50% Hourly Values 1943 - 1944
Maximum value
Value exceeded 10% of time
" " 50% " "
" " 90% " "
MICROVOLTS PER METER
10,000
5,000
2,000
1,000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
10
15
20
30
40
50
60
80
100
150
200
300
400
MILES
FIGURE 3


PERCENTAGE OF THE LISTENING HOURS AND (IN PARENTHESES) THE NUMBER OF LISTENING HOURS (6 AM TO MIDNIGHT) DURING THE LAST SUNSPOT CYCLE (1933-1944) FOR WHICH THE F LAYER SKIP DISTANCE WAS LESS THAN THE VALUES SHOWN FOR PARTICULAR FREQUENCIES. (Estimated from the National Bureau of Standards Ionosphere measurements at Washington, D. C.)
5% (3614 HOURS)
3% (2168 HOURS)
1% (723 HOURS)
0.1% (72 HOURS)
0.01% (7 HOURS)
F LAYER TRANSMISSION EXPECTED FOR 5% OR MORE OF THE TIME
NO F LAYER TRANSMISSION IN THIS REGION
SKIP DISTANCE IN MILES
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
FREQUENCY IN MEGACYCLES
FIGURE 4

ESTIMATED INTERFERENCE TO A FM STATION AT NEW YORK CITY FROM SIX HIGH POWERED CO-CHANNEL STATIONS AT DISTANCES OF 2500 MILES OR MORE WHEN 4 HOURS INTERFERENCE IS EXPECTED FROM A SINGLE STATION AT 2500 MILES

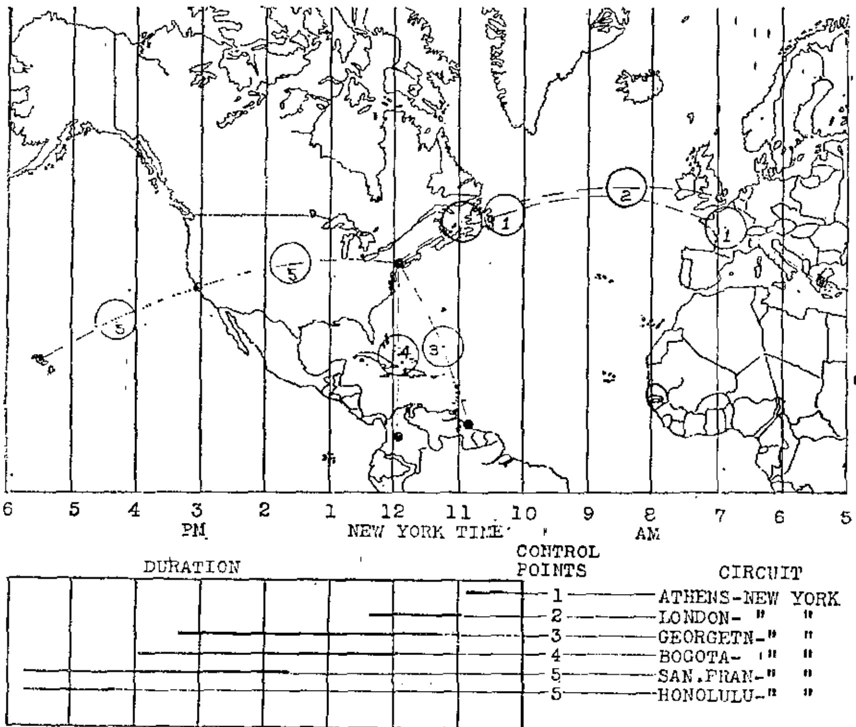


FIGURE 5

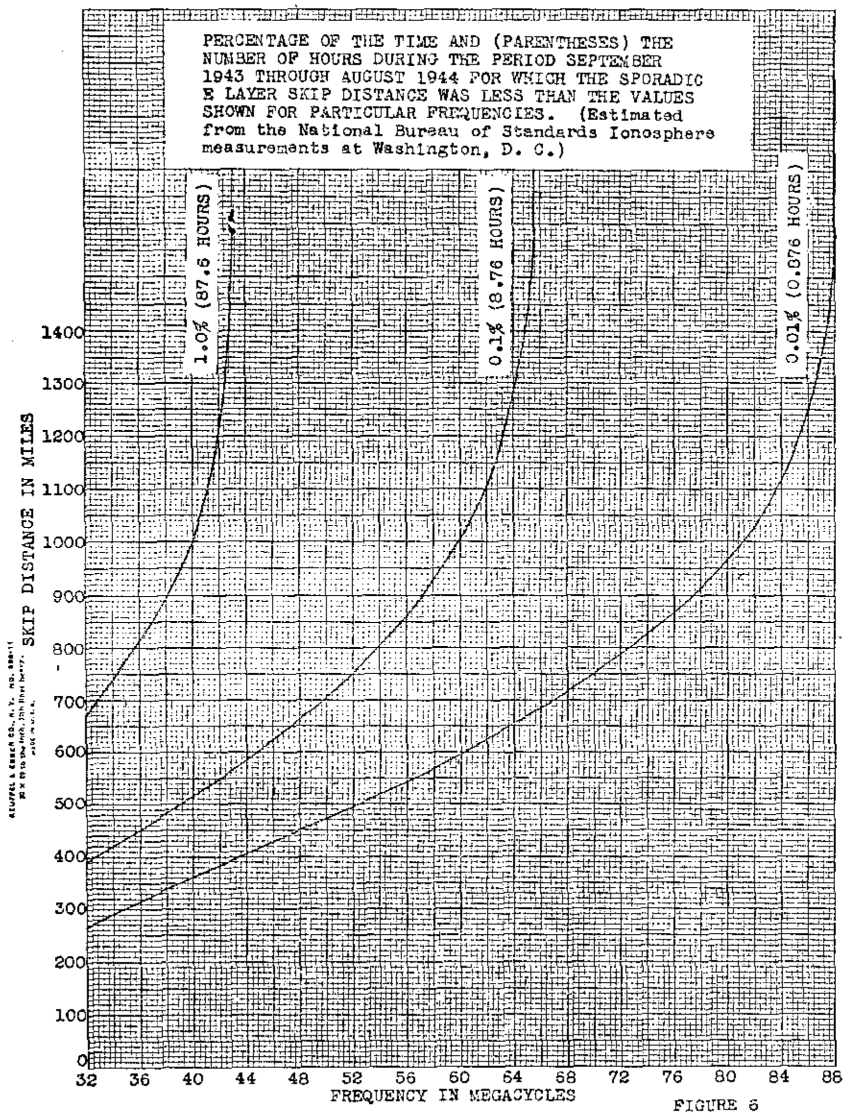

PERCENTAGE OF THE TIME AND (PARENTHESES) THE NUMBER OF HOURS DURING THE PERIOD SEPTEMBER 1943 THROUGH AUGUST 1944 FOR WHICH THE SPORADIC E LAYER SKIP DISTANCE WAS LESS THAN THE VALUES SHOWN FOR PARTICULAR FREQUENCIES. (Estimated from the National Bureau of Standards Ionosphere measurements at Washington, D. C.)
1.0% (87.6 HOURS)
0.1% (8.76 HOURS)
0.01% (0.876 HOURS)
SKIP DISTANCE IN MILES
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
FREQUENCY IN MEGACYCLES

FIGURE 5

GEOGRAPHICAL SEPARATION OF E LAYER CONTROL POINTS FOR ESTIMATING INTERFERENCE TO A KANSAS CITY STATION FROM NINE STATIONS LOCATED 800 MILES DISTANT

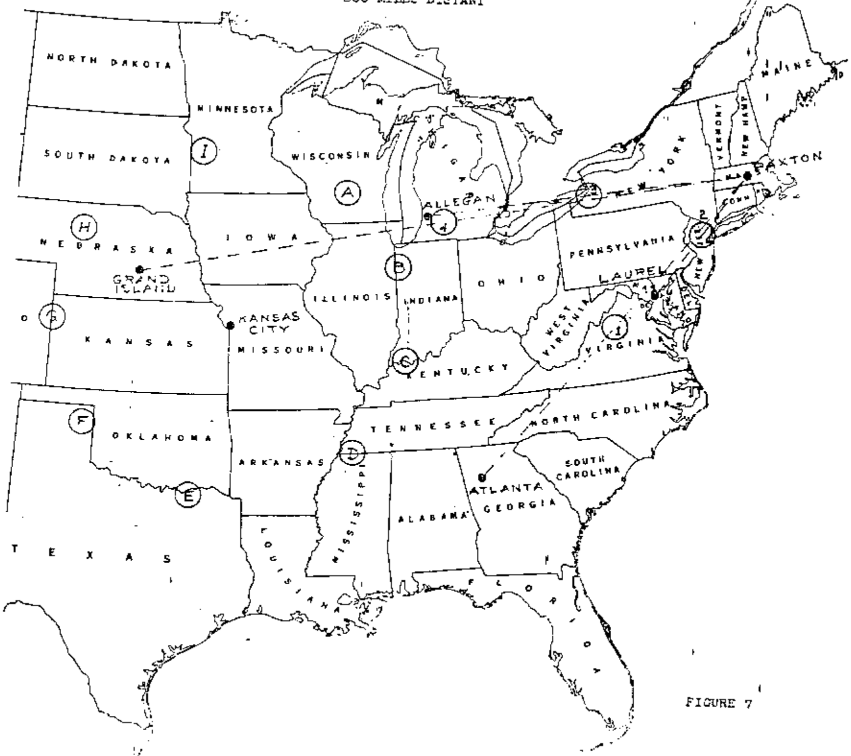


FIGURE 7

GROUND WAVE, TROPOSPHERIC WAVE, SPORADIC E LAYER SKY WAVE AND F LAYER SKY WAVE FIELD INTENSITIES FOR FM STATION WGTR AT PAXTON, MASSACHUSETTS

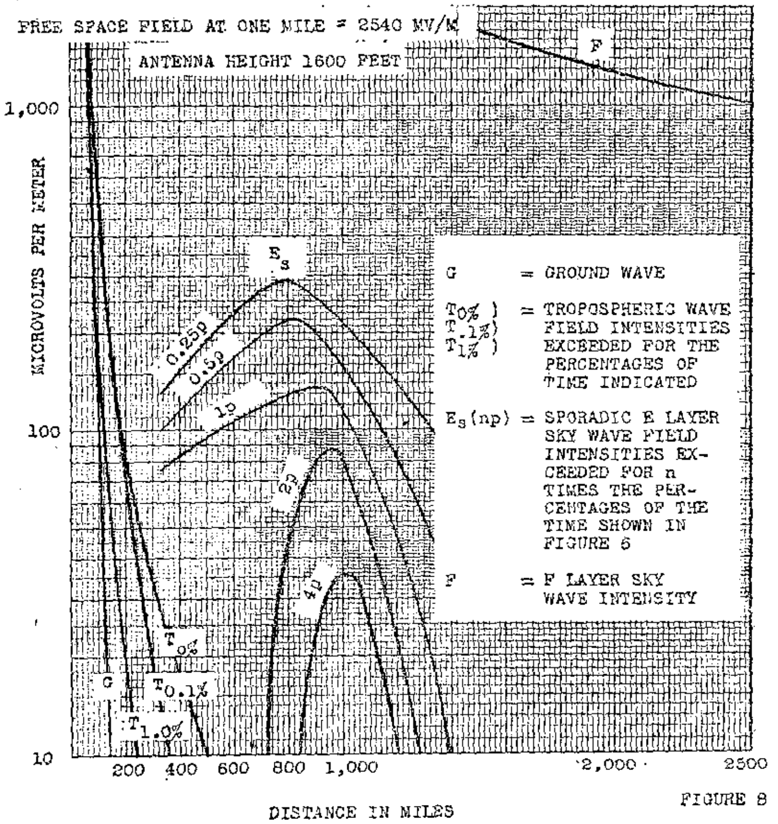


FIGURE 8

COMPARISON OF FM SERVICE AREAS AVAILABLE ON 46 AND 105 MC

TRANSMITTING AND RECEIVING ANTENNA HEIGHTS 500 FEET AND 30 FEET
SIX DECIBELS ALLOWED FOR IRREGULARITIES OF THE TERRAIN

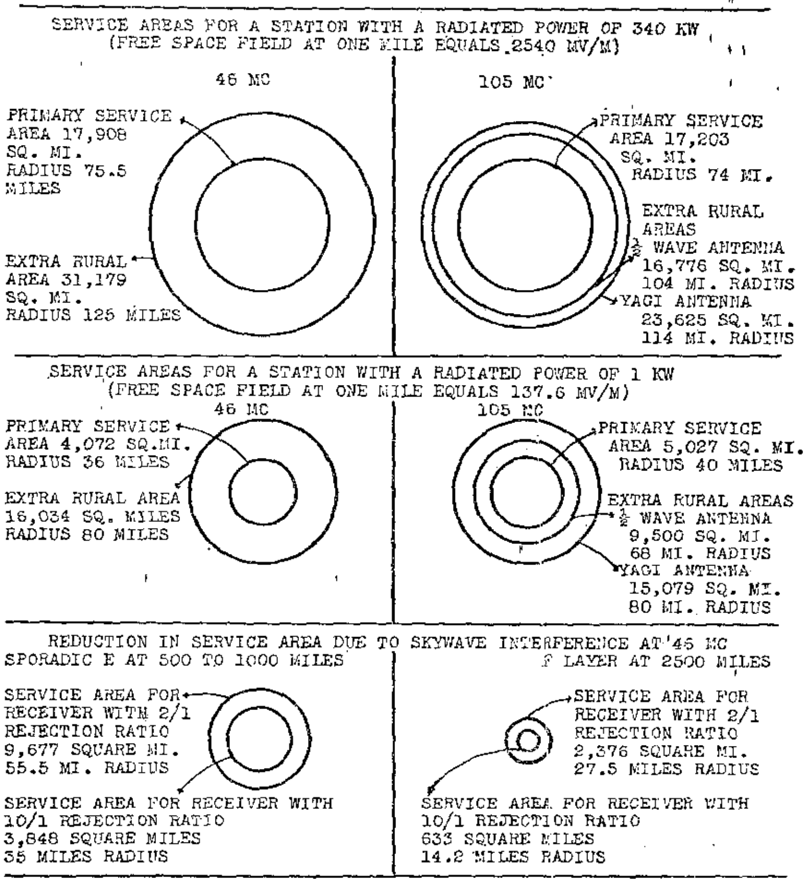


FIGURE 9